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(54) **CIRCUIT FOR MEASURING SOURCE RESISTANCE OF A SENSOR**

SENSORWIDERSTANDMESSSCHALTUNG

CIRCUIT PERMETTANT DE MESURER LA RESISTANCE DE SOURCE D'UN CAPTEUR

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Description

BACKGROUND OF THE INVENTION

[0001] This invention relates to a circuit for measuring a source resistance of a sensor. In particular, this invention provides for measurement of the source resistance of the sensor by applying a known test current to the sensor to obtain substantially stable voltages, and measuring the resulting voltages to calculate the source resistance.

[0002] Continuous measurement of electrodes in a solution is known throughout the art. For example, Blackmer in U.S. Patent 3,661,748 discloses a device in which an ac signal is applied via an electrode to the conductive fluid in which the electrode system is disposed. An ac signal detector is connected to the dc circuitry to measure the ac current flow. A threshold circuit responsive to the output of the ac signal detector indicates fault in the electrochemical sensor system when the output is of a predetermined magnitude. The system measures a change in resistance of the electrode membrane by a phase detector using the ac signal source as a phase reference. A resistance threshold is provided such that an alarm will sound when the threshold is exceeded.

[0003] Connery et al., U.S. Patent 4,189,367 disclose another system for testing electrodes. In Connery et al., the electrodes comprise a glass membrane pH electrode and a reference electrode. The membrane is tested for damage during periodic testing periods by applying a test current through the electrodes and measuring the corresponding changing voltages produced between the electrodes. A reverse current of the same magnitude and duration is then applied through the electrode system to discharge capacitance. The test system does not test the reference electrode and pH electrode separately.

[0004] While it is important to monitor sensor electrodes while the sensing system is in use, it is desirable to do this quickly, with low power consumption, and without corrupting the data signal. Some prior art systems are very slow because capacitors are used to measure resistance. Very large resistances have large RC time constants which makes measurement slow. Many prior art systems are not properly isolated or shielded, thus allowing stray capacitances to effect the values being measured.

[0005] Previous prior art systems have also disclosed that bulk resistances of a membrane, such as a glass membrane, can be measured by passing a unidirectional test current through the glass and measuring the resultant voltage drop to calculate the resistance. A unidirectional current would not be acceptable in a continuously monitoring system such as the present invention because the electrode would be polarized and would produce erroneous results.

SUMMARY OF THE INVENTION

[0006] The present invention provides a fast acting apparatus to measure the resistance of a sensor in a substance without substantially upsetting the data due to sampling by applying a known test current to the sensor. The sensor can have virtually any input resistance.

[0007] Generally, the apparatus injects a first test current into the sensor and then measures a substantially stable first voltage level across the sensor when the first test current is present. The apparatus then injects a second test current into the sensor, the second test current being substantially equal to but opposite in polarity to the first test current. A substantially stable second voltage level across the sensor is measured when the second test signal is present. Using the first measured voltage level and the second measured voltage level, the apparatus calculates the resistance of the sensor.

[0008] In a preferred embodiment, an oscillating signal is generated to drive the apparatus of the present invention. Portions of the oscillating signal are then made available at inputs of a differential amplifier. The differential amplifier provides the positive test current and negative test current repetitively to the sensor.

[0009] The differential amplifier is connected to the sensor by means of coaxial cable. The coaxial cable is bootstrapped to reduce the effect of input capacitance, and to improve the speed of the apparatus. The result of the present invention is that the sensor resistance can be measured simultaneously and on a continuous basis without upsetting readings corresponding to the sensor source voltage.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010]

Figure 1 is a circuit diagram of a measuring apparatus of the present invention;
Figure 2 is a circuit diagram of an analog output portion of the circuit of Figure 1;
Figure 3 is a timing diagram showing the on times and off times of voltages at various points of the circuit of Figure 1;
Figures 4A and 4B are a schematic and block diagram of a second embodiment of the present invention; and

Figures 5A and 5B together are a partial detailed circuit diagram of the circuit of Figures 4A and 4B.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0011] The present invention provides an apparatus to measure the source resistance of a sensor by injecting a known test current. Source resistance is the internal resistance of the sensor along with any external conditions such as coating or cracking of the sensor, which together may change the total resistance of the sensor as measured from a monitoring device connected to the sensor.

[0012] These sensors further produce a source voltage that is received by the monitoring device. The source voltage is a signal representing a parameter or condition that the sensor is measuring. It should be understood, that the present invention will be described with reference to a pH sensor but the present invention is applicable to other sensors with a broad range of source resistances such as selective ion sensors, oxygen sensors and the like.

[0013] Source resistance can be measured by injecting a known test current into a test electrode. The resultant change in voltage divided by the test current is equal to the source resistance. In the present invention, a test current is to be injected into the electrode alternately in each polarity with equal magnitude and time duration. By injecting current in this manner, the total average charge to the electrode will be zero for a complete test cycle. For a pH electrode, application of a reverse current discharges capacitance in the electrode and prevents unidirectional ionic migration in the electrode glass. The resultant voltages caused by the switched test current will be stored and then sampled. By taking the sum and difference of the resultant voltages, the source voltage and source resistance can be calculated. An alternative way to calculate the resistance and voltage of the sensor is to digitize the resultant voltages with an analog to digital (A/D) converter and have a microprocessor compute the source voltage as well as the source resistance.

[0014] Calculating the source resistance allows the user to determine the integrity of the sensor and thus determine the relative accuracy of the sensor system. Sensor systems which have electrodes immersed in solutions, such as pH sensors, may become coated over time. Electrodes that get coated over time slowly increase in resistance. To protect against using a sensor system with over-coated electrodes, the user preselects a maximum allowable resistance into a microprocessor and when that value is sensed by the circuit of the present invention a fault indicator informs the user that replacement, maintenance, and/or recalibration is necessary. In the same way, electrodes may become cracked or broken. The characteristic of a cracked or broken electrode is a sharp decrease in electrode resistance. In this case, the user preselects a minimum value for the electrode resistance into the microprocessor. If, and when this value is detected by the circuit, a fault signal is generated.

[0015] Figure 1 illustrates a schematic and block diagram circuit of an input portion of the resistance measuring apparatus of the present invention. A sensor, shown generally at 10, is connected across terminals 20A and 20B, has an source resistance 12 R_s and an source voltage 14 e_s. A positive test current i_{t+}, represented by arrow 16, and a negative test current i_{t-}, represented by arrow 17, are injected through resistor 18 into the sensor 10 at terminal 20A resulting in a corresponding voltage e_n produced across the terminals 20A and 20B. Terminal 20A is connected via a coaxial cable 22 to input 21 of an amplifier 24. The shield of coaxial cable 22 is connected to input 23 of amplifier 24.

[0016] Amplifier 24, is a voltage follower amplifier with high resistance input and very low bias current, which means the bias current is much less than the injected current through the sensor 10. For sensors that have high source resistance, an amplifier with very high amplifier resistance would be the best. Since amplifier 24 is a voltage follower amplifier, an output voltage e_o at an output terminal 26 of amplifier 24 is substantially equal to the input voltage at terminal 21.

[0017] As illustrated, the coaxial cable 22 is boot-strapped to reduce the effective input capacitance and to improve the speed of the sensor 10. Boot-strapping is done by driving the coaxial shield and surrounding guard straps of cable 22 with the output voltage at terminal 26. Since the voltage at terminal 26 is equal to the voltage at terminal 21, there is no voltage change across the cable 22 and thus, the coaxial capacitance of cable 22 does not inject charge into the input terminal 21.

[0018] The voltage at terminal 26 drives a differential amplifier 28 which includes resistors 30, 32, 34 and 36. The resistors 30 and 34 are equal to each other and collectively will be referred to as R_F. The resistors 32 and 36 are also equal to each other and collectively will be referred to as R_N. It is very important that resistors 30 and 34 are matched to equal each other and that resistors 32 and 36 are also equal to each other since errors in the injected current through resistor 18 would result if each of the above-mentioned resistor pairs were not matched. The differential amplifier 28 produces an output voltage e_t at terminal 38 as a result of input voltages e_1 and e_2 applied to signal lines 40 and 42, respectively, according to the equation below where the gain of the amplifier 28 is R_F/R_N.

$$e_t = [(e_2 - e_1)\frac{R_f}{R_n}] + e_o \qquad \text{EQUATION (1)}$$

[0019] If the voltage e_1 on signal line 40 is equal to the voltage e_2 on signal line 42, then the output voltage e_t at

terminal 38 would be equal to the voltage e_o at terminal 26 and the voltage e_n at terminal 20A. If the voltage e_t is equal to the voltage e_n, then there would be no voltage across resistor 18 and therefore no current will be injected into the sensor 10.

[0020] Switches 44A, 44B, 46A and 46B control the voltage applied to signal lines 40 and 42. For instance, if switch 44A is closed and switch 44B is open, a positive reference voltage e_{ref+} at terminal 52 is applied to signal line 40. Similarly, if switch 44B is closed and switch 44A is open, a negative reference voltage e_{ref-} at terminal 54 will be applied to signal line 40. Switch 44B is tied to signal line 45 as is switch 44A but switch 44B operates opposite to switch 44A so that switch 44B is always closed when switch 44A is open and vice-versa. Switches 46A and 46B are similar to switches 44A and 44B and are connected to signal line 47 with switch 46B operating opposite to that of switch 46A. Thus, if switch 46A is closed and switch 46B is open, the positive reference voltage e_{ref+} at terminal 52 is applied to signal line 42. Whereas, if switch 46B is closed and switch 46A is open, the negative reference voltage e_{ref-} at terminal 54 is applied to signal line 42.

[0021] A timing logic system 56 provides control signals on signal lines 45 and 47 and this activates switches 44A, 44B, 46A and 46B. An oscillator 58 drives the timing logic system 56 with a suitable signal provided on signal line 57. By controlling the switching of switches 44A, 44B, 46A and 46B, the timing logic system 56 generates the injector test currents i_{t+} and i_{t-} as represented by arrows 16 and 17, respectively. For instance, by switching the signal line 42 to the positive reference voltage e_{ref+} at terminal 52 while the signal line 40 is connected to the negative reference voltage e_{ref-} at terminal 54, the positive test current i_{t+} will flow through resistor 18. The value of the positive test current i_{t+} is represented by the following equation.

$$i_{t+} = \frac{(e_{ref+} - e_{ref-})\,\frac{R_F}{R_N}}{R_{18}} \qquad \textbf{EQUATION (2)}$$

[0022] Whereas, switching the signal line 40 to the positive reference e_{ref+} at terminal 52 while the signal line 42 is connected to the negative reference voltage e_{ref-} at terminal 54 generates the negative test current i_{t-} which will flow through resistor 18 in an opposite direction from i_{t+} 16. The value of the negative test current i_{t-} is represented by the following equation.

$$i_{t-} = \frac{(e_{ref-} - e_{ref+})\,\frac{R_F}{R_N}}{R_{18}} \qquad \textbf{EQUATION (3)}$$

[0023] It should be noted that there are other ways to generate the test currents i_{t+} and i_{t-}. For example, the signal line 40 could be grounded and a symmetrical oscillating voltage above and below ground could be applied to the signal line 42. Alternatively, the signal line 42 could be grounded and the symmetrical oscillating voltage could be applied to the signal line 40.

[0024] The voltage across terminals 20A and 20B when the test current i_{t+} 16 is applied is given by the following equation:

$$e_n = e_s + i_{t+} R_s \qquad \text{EQUATION (4)}$$

[0025] Likewise, when i_{t-} 17 is applied to the sensor 10 the voltage across terminals 20A and 20B is given by the following equation:

$$e_n = e_s + i_{t-} R_s \qquad \text{EQUATION (5)}$$

[0026] The timing logic circuit 56 also controls a sample and hold circuit comprising switches 48 and 50 and capacitors 60 and 62. Signal lines 49 and 51 connect the timing logic circuit 56 to switches 48 and 50, respectively. The capacitors 60 and 62 are used to store the output voltages produced at terminal 26 when the positive test current i_{t+}

and the negative test current i_{t-} are generated.

[0027] The timing diagram of Figure 3 illustrates operation of the circuit of Figure 1. A timing signal 61 corresponds to the signal generated on signal line 45, while a timing signal 63, opposite in phase to timing signal 61, corresponds to the signal generated on signal line 47. As described above, the signal lines 45 and 47 are used to control operation of the switches 44A, 44B, 46A and 46B in order to generate the positive test current i_{t+} and the negative test current i_{t-}. For instance, during a time duration from T_1 to T_2, the signal 61 applied to the signal line 45 is low, while the signal 63 applied to the signal line 47 is high, which in turn closes switches 44B and 46A and opens switches 44A and 46B. As stated above, this causes a positive test current i_{t+} to flow through resistor 18 thereby producing an increasing output voltage e_o at terminal 26 as represented by a signal line 65. The rise time illustrated in signal line 65 is caused by stray distributive capacitance and the internal resistance R_S 12 of the sensor 10 as well as the non-ideal operation of the amplifiers. When the output voltage e_o is substantially stable having reached its peak value, the switch 48 is operated through signal line 49 as represented by a timing signal 69 illustrated in Figure 3. The corresponding peak output positive voltage e_{o+} is thus stored on capacitor 60.

[0028] Similar operation is performed to a peak output negative voltage e_{o-} when the negative test current i_{t-} is generated. Referring to the time duration from T_2 to T_3, the signal 61 applied to the signal line 45 is high, while the signal 63 applied to the signal line 47 is low, which in turn opens switches 44B and 46B and closes switches 44A and 46B. As stated above, this causes the negative test current i_{t-} to flow through resistor 18 thereby producing a decreasing output voltage e_o at terminal 26 as represented by the signal line 65. When the output voltage e_o is substantially stable having reached its lowest peak value, the switch 50 is operated through signal line 51 as represented by a timing signal 71 illustrated in Figure 3. The corresponding peak output negative voltage e_{o-} is thus stored on capacitor 62. Preferably, as illustrated in Figure 3, the above-described sequence continues repetitively throughout operation of the sensor.

[0029] Referring back to Figure 1, amplifiers 64 and 66 receive the values held on capacitors 60 and 62, respectively. The amplifiers 64 and 66 are connected as voltage followers. The amplifier 64 provides a voltage signal on a signal line 73 corresponding to the peak output positive voltage e_{o+}, while the amplifier 66 provides a voltage signal on a signal line 75 corresponding to the peak negative voltage e_{o-}.

[0030] Figure 2 illustrates a simple circuit connected to the circuit of Figure 1 that is capable of calculating the source voltage e_S and the source resistance R_S. The source voltage e_S is calculated using resistors 68 and 70, and an amplifier 74. As illustrated, the resistor 68 is connected to signal line 73, while the resistor 70 is connected to signal line 75. The resistors 68 and 70 are equal to each other and are connected together at a node 72, which is in turn connected to a positive input of the amplifier 74. The resistors average the voltages present on the signal lines 73 and 75 wherein the voltage at node 72 is equal to $(e_{o+} + e_{o-})/2$. The amplifier 74, being connected as a voltage follower, receives the value provided at node 72 and makes that value available on a signal line 79 for displaying or for use in later calculations.

[0031] A differential amplifier circuit 81 also connected to signal lines 73 and 75 is used to calculate the input resistance R_s of sensor 10. The differential amplifier circuit 81 comprises resistors 76, 78, 80 and 82 and an amplifier 84. The resistors 76, 78, 80 and 82 are all equal to each other, which in turn makes differential amplifier 84 have a unity voltage gain. Since the output of a differential amplifier circuit is equal to the difference between the incoming signals multiplied by the gain of the amplifier, and since the gain of the amplifier circuit 81 is unity, an output terminal 86 of amplifier 84 is equal to the difference of the voltages on signal lines 73 and 75, or the quantity $(e_{o+} - e_{o-})$. With the voltage at terminal 86 equal to the quantity $(e_{o+} - e_{o-})$, the source resistance R_s of the sensor 10 can be calculated by dividing by two times the value of the positive test current i_{t+} or the negative test current i_{t-}.

[0032] A schematic, block diagram of an alternative preferred embodiment of the present invention is illustrated in Figures 4A and 4B. In Figures 4A and 4B, like elements from Figures 1 and 2 are correspondingly numbered. Figures 4A and 4B illustrate a dual channel sensing system 99 having a test current injection and voltage measuring circuit 101 and an output circuit 103.

[0033] The dual channel system 99 measures the source resistance and source voltage of each electrode of an ion sensor system comprising a glass pH electrode 10 and a reference electrode 100. It should be noted that the reference electrode can comprise an ion selective electrode such as disclosed in U.S. Patent 3,862,985 issued to King et al. As illustrated in Figure 4A, this electrode comprises a reservoir 100A filled with a pH buffer solution 100B having a porous junction 100C in contact with the test solution to be tested.

[0034] Referring to connection of the circuit 101 to the pH electrode 10, test currents of equal magnitudes and opposite polarity are injected into the pH electrode 10 in the manner described above with the differential amplifier circuit connected to amplifier 28. Reference voltages on the signal lines 40 and 42 are provided from an oscillator and demodulator circuit generally indicated at 106 and described in detail below. As with the circuit illustrated in Figure 1 and described above, the voltage produced at the terminal 26 of the amplifier 24 corresponds to the signal line 65 in Figure 3. This output voltage is provided back to the circuit 106.

[0035] A reference portion of the circuit illustrated in Figures 4A and 4B are shown generally at 104 in dashed lines. The reference portion 104 is connected to the reference electrode 100 and is substantially identical to the test current

injection and voltage measuring circuit of the pH electrode 10. To identify like components, numeric designations have been repeated with circuit elements of the reference portion 104 including an additional "R" designation. It should be noted that since the resistance of the reference electrode 100 is considerably less than the resistance of the pH electrode 10, the value of the resistor 18R is less than the value of resistor 18 to allow greater test currents to be injected.

[0036] The timing logic circuit 56 and the switches 44A, 44B, 46A and 46B from Figure 1 have been replaced by the oscillator and demodulator circuit 106. As stated above, the circuit 106 provides test currents to be injected into the pH electrode 10 and the reference electrode 100, while receiving corresponding voltages developed at terminals 26 and 26R. The voltages from terminals 26 and 26R are used to provide signals at output terminals 106A, 106B, 106C and 106D corresponding to the source voltage of the pH electrode, the source resistance of the pH electrode, the source voltage of the reference electrode, and the source resistance of the reference electrode, respectively. Each of the aforementioned signals are provided to suitable voltage followers 108 and 108R, which in turn provide input signals to the output circuit 103 on signal lines 105A, 105B, 105C and 105D.

[0037] The output circuit 103 includes a multiplexer 110, an analog-to-digital ("A/D") converter 112 and central processing unit ("CPU") 114 such as a microprocessor. The multiplexer 110 receives command signals from the CPU 114 to selectively transmit the signals from the input terminals 105A-105D to the A/D converter 112. Digitized data from the A/D converter 112 is provided back to the CPU 114 on a data transmission line 107. Using the digitized data, the CPU 114 provides suitable visual indications of the measured source voltage and source resistance parameters of the pH electrode 10 and reference electrode 100 with a display 116. A conventional 4-20 milliamp output circuit 115 can be included to provide a current signal proportional to each of the measured quantities. Interaction with the system 99 is provided through a suitable interface such as a keyboard 118.

[0038] In addition, since the resistivity of the pH electrode 10 varies with temperature in accordance with well known principles, the system 99 includes a suitable probe 120 to measure the temperature of the monitored solution. Illustrated as a three-wire resistive temperature device, the probe 120 includes conventional "source", "return" and "sense" signal lines, generally indicated at 117, which together provide a signal proportional to the temperature of the solution. Through the A/D converter 112 and the multiplexer 110, the CPU 114 receives digitized data corresponding to the solution temperature and adjusts the measured quantities in accordance with well known factors.

[0039] Also illustrated in Figure 4A is a solution ground probe 11. The solution ground probe 11 allows the user to monitor both the pH electrode 10 and the reference electrode 100 independently for coating or cracking as opposed to only monitoring the entire system if a solution ground probe was not used.

[0040] Figures 5A and 5B illustrate a more detailed diagram of the test current injection and voltage measuring circuit 101 of Figures 4A and 4B. Figures 5A and 5B are connected for illustrative purposes via terminal connections 119, 119R, 121, 121R, 123, 123R, 125 and 125R. As with the diagram illustrated in Figures 4A and 4B, the same numeric designators have been used in the pH electrode monitoring circuit portion and the reference electrode circuit portion to identify like components or circuit portions. Although described with reference primarily to the pH electrode monitoring circuit portion, it is to be understood similar functions are performed by the reference electrode monitoring portions.

[0041] Referring to Figure 5B, the oscillator and demodulator circuit 106 of Figure 4B has been broken down to separate components and is shown together in dashed lines. An analog multiplexer/demultiplexer 130, a counter 134 and a nand gate 136A are provided to handle the demodulating tasks. A voltage comparator 132 configured with resistors 133, 135, 137, 139, and capacitor 140 creates a relaxation oscillator corresponding to the oscillator 58 of Figure 1.

[0042] The binary counter 134 receives the output of the comparator 132 and functions as the timing logic portion 56 of Figure 1. Selected outputs of the binary counter 134 are connected to the nand gate 136A and a nand 136B. The output of the nand gate 136B (provided to the circuit portion illustrated in Figure 5A through terminal connections 121 and 121R) in combination with the input signal received from the binary counter 134 (provided to the circuit portion illustrated in Figure 5a through terminal connections 123 and 123R) provide reference voltages on signal lines 40, 42, 40R and 42R to generate the positive and negative test currents, as described above. Like the embodiment illustrated in Figure 1, voltage signals are obtained at the output terminals 26 and 26R and are a function of the injected test currents.

[0043] In the embodiment illustrated in Figures 5A and 5B, there is no longer a summing circuit or a difference circuit as embodied in Figure 2 to calculate the source voltage and the source resistance, respectively. To calculate the source voltage, for example, the source voltage of the pH electrode, the voltage signal present at output terminal 26 is obtained by applying the signal to a two pole filter 140, which filters out the ac component and provides a substantially dc signal at terminal connection 119 proportional to the value of the source voltage. The two pole filter 140 comprises an amplifier 144, resistors 146, 148, and 149, and capacitors 150 and 152.

[0044] The difference between the peak to peak voltage at terminal 26, which is directly proportional to the source resistance of the electrode, is found by applying the signal at terminal 26 selectively across a capacitor 174 and the series combination of the capacitor 174 and a capacitor 162. In operation, as with the embodiment of Figure 2 as illustrated in Figure 3, the peak to peak voltage levels are selectively sampled when the voltage levels are substantially stable. In the embodiment of Figures 5A and 5B, the control signals for sampling are provided from the output of the nand gate 136A. With respect to Figure 3, the control signal from the nand gate 136A is the additive combination of the sig-

nals 69 and 71.

[0045] Referring also to Figure 3, the signal representing the difference between the voltages e_{o+} and e_{o-} provided from an output terminal 131 of the multiplexer/demultiplexer 130 is applied to a two pole filter 154. Specifically, during the time period T_2 to T_3, the voltage e_{o-} is stored across the capacitor 174 when the voltage e_{o-} is substantially stable and the control pulse (corresponding to signal 71) is received from the nand gate 136A. During the time period T_3 to T_4, the positive test current is injected into the electrode in the manner described above to raise the voltage at the terminal 26 to the level of e_{o+}. When the voltage is substantially stable and the control pulse (corresponding to signal 69) is received, the multiplexer/demultiplexer 130 connects the capacitor 174 in series with the capacitor 162, thereby providing the difference in voltage to the two pole filter 154 and across capacitor 162. As illustrated, the filter 154 comprises an amplifier 156, resistors 158, 160 and 161, and capacitors 164 and 166.

[0046] Filter capacitors 170, 172, and 174 are found in Figures 5A and 5B. These capacitors are standard capacitors and are well known in the art. Also conventionally used are limiting resistors 176 and 177.

[0047] As described above and illustrated in Figure 4A, the coaxial cable 22 is boot-strapped to reduce the effective input capacitance and to improve the speed of the monitoring system. In addition, it should be noted that if embodied on a conventional circuit board, signal traces used to shield the signal lines connecting the coaxial cables 22 and 22R to amplifier 24 should also be boot-strapped or driven with the output voltage from the terminals 26 and 26R, respectively. The shield traces are illustrated in Figure 5A schematically by dashed lines 190 and 190R.

[0048] Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the scope of the invention.

Claims

1. A method for measuring a resistance of a sensor, the method comprising the steps of:

   injecting a first test current (16) and a second test current (17) into the sensor (10), the second test current (17) being substantially equal to but opposite in polarity to the first test current (16), the method being characterized by:
   measuring a substantially stable first voltage level across the sensor (10), the voltage having reached a peak value when the first test current (16) is present;
   measuring a substantially stable second voltage level across the sensor (10), the voltage having reached a peak value when the second test current (17) is present; and
   calculating the resistance of the sensor (10) as a function of the measured first peak voltage level and the measured second peak voltage level.

2. An apparatus for measuring a resistance of a sensor (10), the apparatus comprising:

   means (28,30,32,34,36) for injecting a first test current (16) and a second test current (17) into the sensor (10), the second test current (17) being substantially equal to but opposite in polarity to the first test current (16), the apparatus being characterized by:
   means (60,62;106) for measuring a substantially stable first voltage level and second voltage level across the sensor (10), the voltages having reached peak values when the corresponding first test current and second test current are present; and
   means (81;106) for calculating the resistance of the sensor (10) as a function of the measured first peak voltage level and the measured second peak voltage level.

3. The apparatus of Claim 2 and further comprising means (68,70,74;140) for calculating a source voltage of the sensor (10) as a function of the measured first peak voltage level and the measured second peak voltage level wherein the source voltage is the nominal voltage of the sensor without application of the test currents.

4. The apparatus of Claim 3 wherein the means (68,70,74) for calculating the source voltage comprises an averaging circuit (68,70,74) for averaging the measured first peak voltage level and the second peak voltage level.

5. The apparatus of Claim 3 wherein the means (140) for calculating the source voltage comprises a filtering circuit (140) for filtering the source voltage from the measured first peak voltage level and the second peak voltage level.

6. The apparatus of Claim 2 wherein the means (28,30,32,34,36) for injecting the first test current and the second test current comprises means for generating the first and second test currents (16,17) with a differential circuit (28,30,32,34,36) having a first input (52) and a second input (54) for receiving selected reference control signals.

7. The apparatus of Claim 6 wherein oscillation means (58) is provided for providing the selected reference control signals.

8. The apparatus of Claim 2 wherein the means (81;106) for calculating the resistance of the sensor comprises difference means for obtaining the difference between the first measured peak voltage level and the second measured peak voltage level.

9. The apparatus of Claim 8 wherein the difference means (81) comprises a differential circuit (81).

10. The apparatus of Claim 8 wherein the difference means (106) comprises a demodulating circuit (106).

11. The apparatus of Claim 2, further arranged to measure a resistance of a second sensor (100);

wherein the means (28R,30R,32R,34R,36R) for injecting is adapted to inject a third test current and a fourth test current into the second sensor (100), the fourth test current being substantially equal to but opposite in polarity to the third test current;
wherein the means (106) for measuring is adapted to measure a substantially stable third and fourth voltage level across the second sensor (100), the third and fourth voltages having reached peak values when the corresponding third test current and fourth test current are present; and
wherein the means (106) for calculating is adapted to calculate the resistance of the second sensor (100) as a function of the measured third peak voltage level and the measured fourth peak voltage level.

12. The apparatus of Claim 11 wherein the first-mentioned sensor (10) comprises a selective ion electrode and the second sensor (100) comprises a reference electrode.

13. The apparatus of Claim 12 wherein the reference electrode (100) comprises a second selective ion electrode.

14. The apparatus of Claim 12 and further comprising a ground probe (11) forming a common ground path for the selective ion electrode and the reference electrode.

15. The apparatus of Claim 2 and further comprising a shielded cable connecting the means for measuring to the sensor, wherein the means for measuring includes driving means (24,24R) for driving the shielded cable with an output voltage of the sensor.

Patentansprüche

1. Verfahren für das Erfassen eines Widerstands eines Sensors, wobei das Verfahren folgende Schritte aufweist:

- die Injektion eines traten Teststroms (16) und eines zweiten Teststroms (17) in den Sensor (10), wobei der zweite Teststrom (17) im Vergleich zum ersten Teststrom (16) im wesentlichen gleich stark, jedoch gegensätzlich gepolt ist, und das Verfahren durch folgendes gekennzeichnet ist:

  die Erfassung eines im wesentlichen stabilen ersten Spannungspegels am Sensor (10), wobei die Spannung einen Spitzenwert erreicht hat, wenn der erste Teststrom (16) anliegt;

  die Erfassung eines im wesentlichen stabilen zweiten Spannungspegels am Sensor (10), wobei die Spannung einen Spitzenwert erreicht hat, wenn der zweite Teststrom (17) anliegt; und

  die Berechnung des Widerstands des Sensors (10) als eine Funktion des erfaßten ersten Spitzenspannungspegels und des erfaßten zweiten Spitzenspannungspegels.

2. Vorrichtung für die Erfassung eines Widerstands eines Sensors (10), wobei die Vorrichtung folgendes aufweist:

- eine Injektionsvorrichtung (28, 30, 32, 34, 36) für das Injizieren eines ersten Teststroms (16) und eines zweiten Testetroms (17) in den Sensor (10), wobei der zweite Teststrom (17) im Vergleich zum ersten Teststrom (16) im wesentlichen gleich stark, jedoch gegensätzlich gepolt ist, und die Vorrichtung durch folgendes gekennzeichnet ist:

- eine Erfassungsvorrichtung (60, 62; 106) für das Erfassen eines im wesentlichen stabilen ersten Spannungspegels bzw. eines zweiten Spannungspegels am Sensor (10), wobei die Spannungen jeweils ihren Spitzenwert erreicht haben, sobald der entsprechende erste bzw. zweite Teststrom anliegt; und

- eine Berechnungsvorrichtung (81; 106) für das Berechnen des Widerstands des Sensors (10) als eine Funktion des erfaßten ersten Spitzenspannungspegel und des erfaßten zweiten Spitzenspannungspegels.

3. Vorrichtung nach Anspruch 2, weiter dadurch gekennzeichnet, daß die Vorrichtung weiter eine Berechnungsvorrichtung (68, 70, 74; 140) für das Berechnen einer Quellenspannung am Sensor (10) als eine Funktion des erfaßten ersten Spitzenspannungspegels und des erfaßten zweiten Spitzenspannungspegels aufweist, wobei die Spannung bei Nichtinjektion der Testströme die Nennspannung des Sensors ist.

4. Vorrichtung nach Anspruch 3, dadurch gekennzeichnet, daß die Berechnungsvorrichtung (68, 70, 74) für das Berechnen der Quellenspannung einen Durchschnittsermittlungsschaltkreis (68, 70, 74) für die Ermittlung des Durchschnitts des erfaßten ersten Spitzenspannungspegels und des zweiten Spitzenspannungspegels aufweist.

5. Vorrichtung nach Anspruch 3, dadurch gekennzeichnet, daß die Berechnungsvorrichtung (140) für das Berechnen der Spannung einen Filterschaltkreis (140) aufweist, welcher die Spannung vom erfaßten ersten Spitzenspannungepegel und vom erfaßten zweiten Spitzenspannungspegel herausfiltert.

6. Vorrichtung nach Anspruch 2, dadurch gekennzeichnet, daß die Injektionsvorrichtung (28, 30, 32, 34, 36) für das Injizieren des ersten Testetroms bzw. des zweiten Teststroms eine Erzeugungsvorrichtung für die Erzeugung des ersten bzw. zweiten Teststroms (16, 17) mit Hilfe eines Unterscheidungsschaltkreises (28, 30, 32, 34, 36) aufweist, wobei der Unterscheidungsschaltkreis einen ersten Eingang (52) und einen zweiten Eingang (54) für den Empfang der selektierten Bezugssteuersignale aufweist.

7. Vorrichtung nach Anspruch 6, dadurch gekennzeichnet, daß eine Oszillationsvorrichtung (58) für die Lieferung der selektierten Bezugssteuersignale vorgesehen ist.

8. Vorrichtung nach Anspruch 2, dadurch gekennzeichnet, daß die Berechnungsvorrichtung (81; 106) für die Berechnung des Widerstands des Sensors eine Unterscheidungsvorrichtung für den Erhalt des Unterschieds zwischen dem ersten erfaßten Spitzenspannungspegel und dem zweiten erfaßten Spitzenspannungspegel aufweist.

9. Vorrichtung nach Anspruch 8, dadurch gekennzeichnet, daß die Unterscheidungsvorrichtung (81) einen Unterscheidungsschaltkreis (81) aufweist.

10. Vorrichtung nach Anspruch 8, dadurch gekennzeichnet, daß die Unterscheidungsvorrichtung (106) einen Demodulationsschaltkreis (106) aufweist.

11. Vorrichtung nach Anspruch 2, ferner so angeordnet, daß ein Widerstand eines zweiten Sensors (100) erfaßt wird, dadurch gekennzeichnet, daß

- die Injektionsvorrichtung (28R, 30R, 32R, 34R, 36R) angepaßt ist, um einen dritten Teststrom und einen vierten Testetrom in den zweiten Sensor (100) zu injizieren, wobei der vierte Teststrom im Vergleich zum dritten Teststrom im wesentlichen gleich stark, jedoch gegensätzlich gepolt ist;

- die Erfassungsvorrichtung (106) so angepaßt ist, daß sie einen im wesentlichen stabilen ersten und zweiten Spannungspegel am zweiten Sensor (100) erfaßt, wobei die die dritte und vierte Spannung jeweils ihren Spitzenwert erreicht haben, sobald der entsprechende dritte bzw. vierte Teststrom anliegt; und

- die Berechnungsvorrichtung (106) so angepaßt ist, daß sie den Widerstands des zweiten Sensors (100) als eine Funktion des erfaßten dritten Spitzenspannungspegel und des erfaßten vierten Spitzenspannungspegels berechnet.

12. Vorrichtung nach Anspruch 2, ferner dadurch gekennzeichnet, daß der erstgenannte Sensor (10) eine selektive Ionenelektrode und der zweite Sensor (100) eine Bezugselektrode aufweist.

13. Vorrichtung nach Anspruch 12, dadurch gekennzeichnet, daß die Bezugselektrode (100) eine zweite selektive

Ionenelektrode aufweist.

14. Vorrichtung nach Anspruch 12, welche weiter einen Erdmeßfühler (11) umfaßt, der einen gemeinsamen Erdweg für die selektive Ionenelektrode und die Bezugselektrode bildet.

15. Vorrichtung nach Anspruch 2, welche ferner ein abgeschirmtes Kabel aufweist, das die Erfassungsvorrichtung mit dem Sensor verbindet, dadurch gekennzeichnet, daß die Erfassungsvorrichtung eine Treibervorrichtung (24, 24R) für den Antrieb des abgeschirmten Kabels mit einer Ausgangespannung des Sensors aufweist.

Revendications

1. Procédé pour mesurer une résistance d'un capteur, le procédé comprenant les étapes consistant à:

   injecter un premier courant de test (16) et un second courant de test (17) dans le capteur (10), le second courant de test (17) étant sensiblement égal, mais avec une polarité opposée, au premier courant de test (16),
   le procédé étant caractérisé par:
   la mesure d'un premier niveau de tension substantiellement stable aux bornes du capteur (10), la tension ayant atteint une valeur de pic lorsque le premier courant de test (16) est présent;
   la mesure d'un second niveau de tension substantiellement stable aux bornes du capteur (10), la tension ayant atteint une valeur de pic lorsque le second courant de test (17) est présent; et
   le calcul de la résistance du capteur (10) en fonction du premier niveau de tension de pic mesuré et du second niveau de tension de pic mesuré.

2. Appareil pour la mesure d'une résistance d'un capteur (10), l'appareil comprenant

   des moyens (28,30,32,34,36) pour injecter un premier courant de test (16) et un second courant de test (17) dans le capteur (10), le second courant de test (17) étant sensiblement égal, mais avec une polarité opposée, au premier courant de test (16),
   l'appareil étant caractérisé par:
   des moyens (60,62;106) pour mesurer un premier niveau de tension substantiellement stable et un second niveau de tension aux bornes du capteur (10), les tensions ayant atteint des valeurs maximales lorsque les premier et second courants de test correspondants sont présents; et
   des moyens (81;106) pour calculer la résistance du capteur (10) en fonction du premier niveau de tension de pic mesuré et du second niveau de tension de pic mesuré.

3. Appareil selon la revendication 2, et comportant en outre des moyens (68,70,74;140) pour calculer une tension de source du capteur (10) en fonction du premier niveau de tension de pic mesuré et du second niveau de tension de pic mesuré, la tension de la source étant la tension nominale du capteur sans l'application des courants de test.

4. Appareil selon la revendication 3, dans lequel les moyens (68,70,74) pour le calcul de la tension de source comprennent un circuit de formation de la moyenne (68,70,74) pour former la moyenne du premier niveau de tension de pic et du second niveau de tension de pic mesurés.

5. Appareil selon la revendication 3, dans lequel les moyens (140) pour le calcul de la tension de source comprennent un circuit de filtrage (140) pour filtrer la tension de source à partir du premier niveau de tension de pic mesuré et du second niveau de tension de pic mesuré.

6. Appareil selon la revendication 2, dans lequel les moyens (28,30,32,34,36) pour l'injection du premier courant de test et du second courant de test comprennent des moyens pour produire les premier et second courants de test (16,17), avec un circuit différentiel (28,30,32,34,36) possédant une première entrée (52) et une seconde entrée (54) pour recevoir des signaux de commande de référence sélectionnés.

7. Appareil selon la revendication 6, dans lequel des moyens oscillants (58) sont prévus pour délivrer les signaux de commande de référence sélectionnés.

8. Appareil selon la revendication 2, dans lequel les moyens (81;106) pour le calcul de résistance du capteur comprennent des moyens de formation de différence pour déterminer la différence entre le premier niveau de tension de pic mesuré et le second niveau de tension de pic mesuré.

9. Appareil selon la revendication 8, dans lequel les moyens de formation de différence (81) comprennent un circuit différentiel (81).

10. Appareil selon la revendication 8, dans lequel les moyens de formation de différence (106) comprennent un circuit de démodulation (106).

11. Appareil selon la revendication 2, agencé en outre de manière à mesurer la résistance d'un second capteur (100);

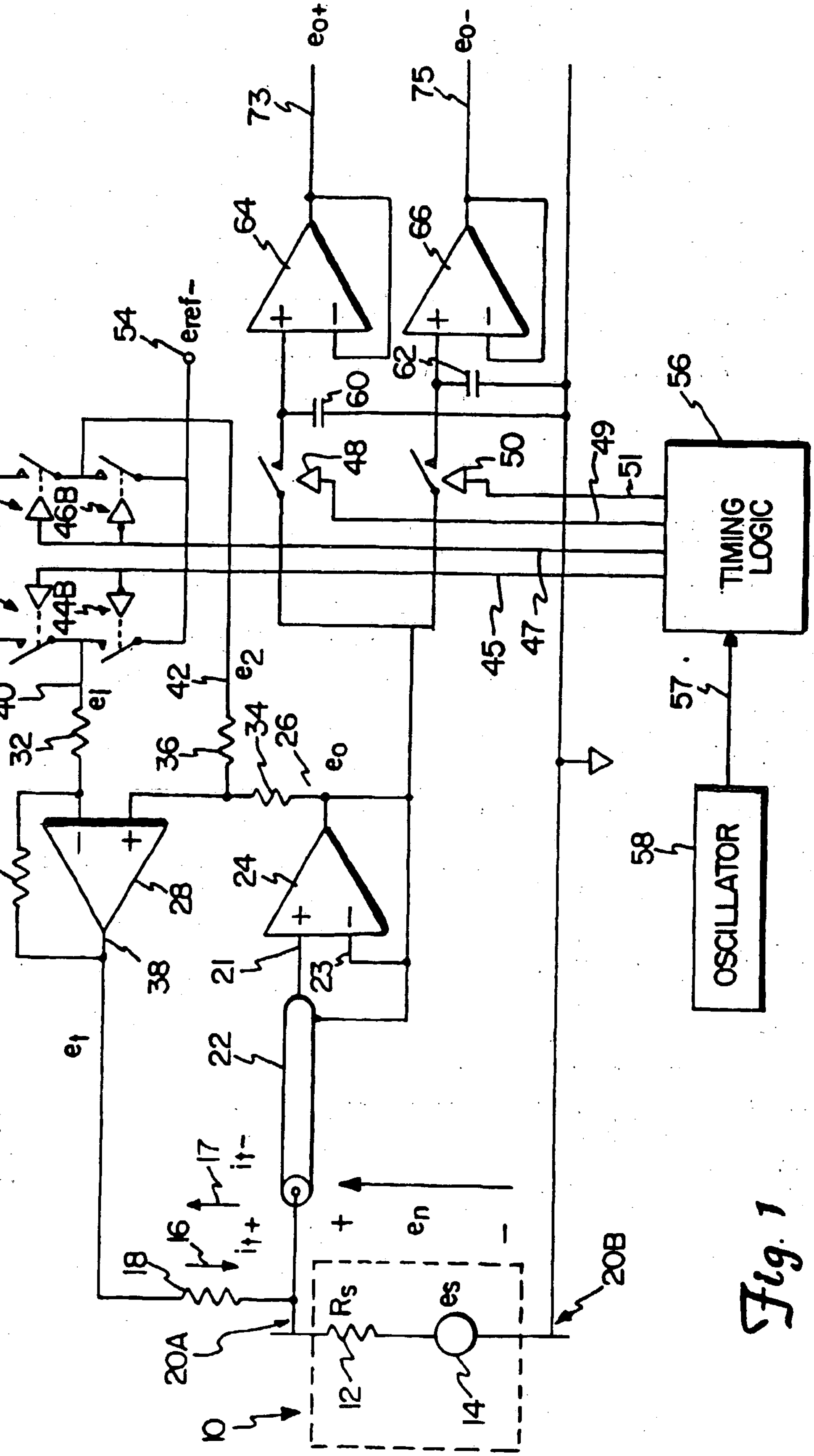
dans lequel les moyens d'injection (28R,30R,32R, 34R,36R) sont adaptés pour injecter un troisième courant de test et un quatrième courant de test dans le second capteur (100), le quatrième courant de test étant sensiblement égal, mais avec une polarité opposée, au troisième courant de test;
dans lequel les moyens de mesure (106) sont adaptés pour mesurer des troisième et quatrième niveaux de tension substantiellement stables aux bornes du second capteur (100), les troisième et quatrième tensions ayant atteint des valeurs maximales lorsque le troisième courant de test et le quatrième courant de test correspondants sont présents; et
dans lequel les moyens de calcul (106) sont adaptés pour calculer la résistance du second capteur (100) en fonction du troisième niveau de tension de pic mesuré et du quatrième niveau de tension de pic mesuré.

12. Appareil selon la revendication 11, dans lequel le capteur (10) mentionné en premier comprend une électrode sélective pour les ions et le second capteur (100) comprend une électrode de référence.

13. Appareil selon la revendication 12, dans lequel l'électrode de référence (100) comprend une seconde électrode sélective pour les ions.

14. Appareil selon la revendication 12, et comportant en outre une sonde de masse (11) formant un trajet de masse commun pour l'électrode sélective pour les ions et l'électrode de référence.

15. Appareil selon la revendication 2 et comprenant en outre un câble blindé reliant les moyens de mesure au capteur, les moyens de mesure comprenant des moyens d'activation (24,24R) pour activer le câble blindé avec une tension de sortie du capteur.



TIMING LOGIC
OSCILLATOR
eref+
eref-
eo+
eo-
eo
e1
e2
et
en
es
Rs
it+
it-
10
12
14
16
17
18
20A
20B
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23
24
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32
34
36
38
40
42
44A
44B
45
46A
46B
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64
66
73
75

Fig. 1

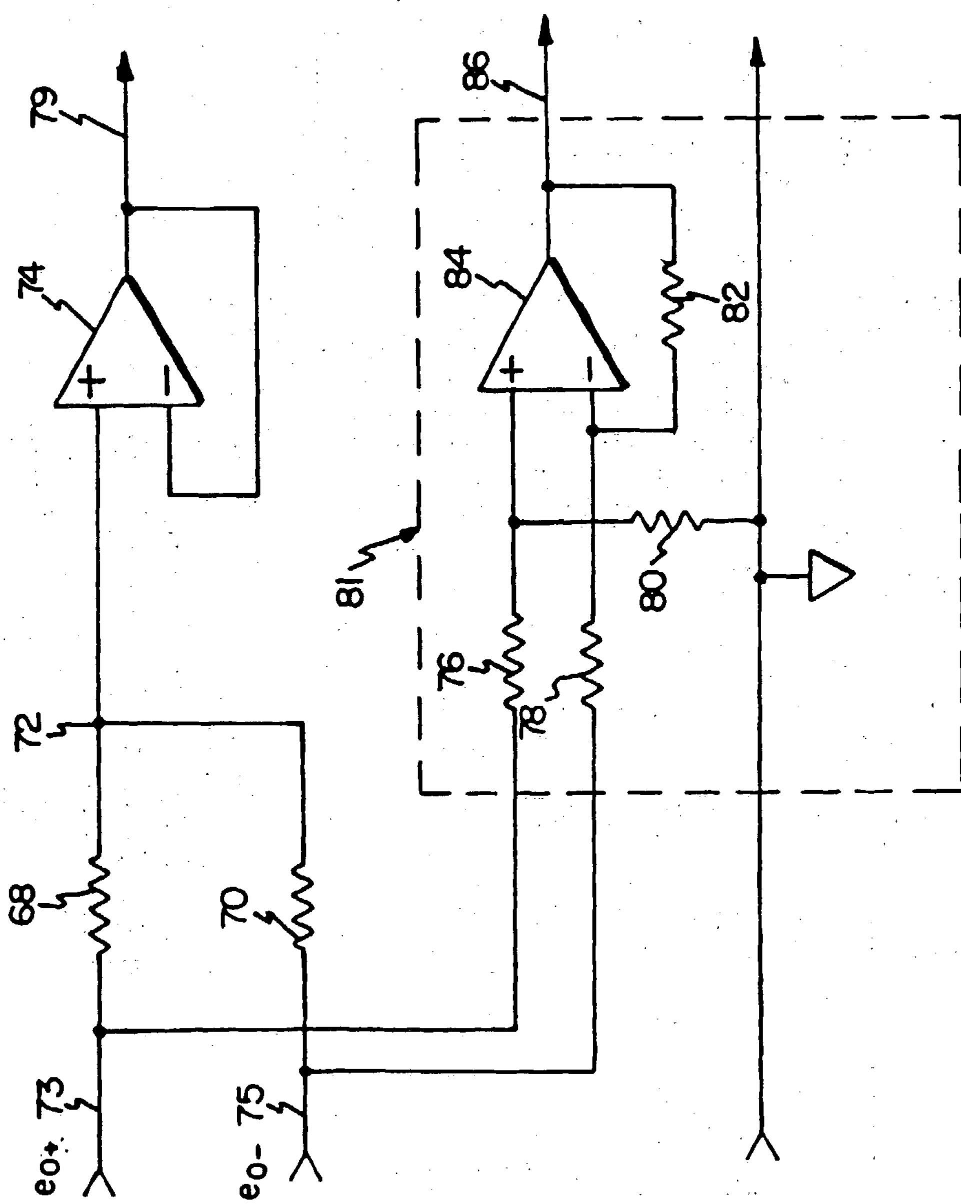


Fig. 2

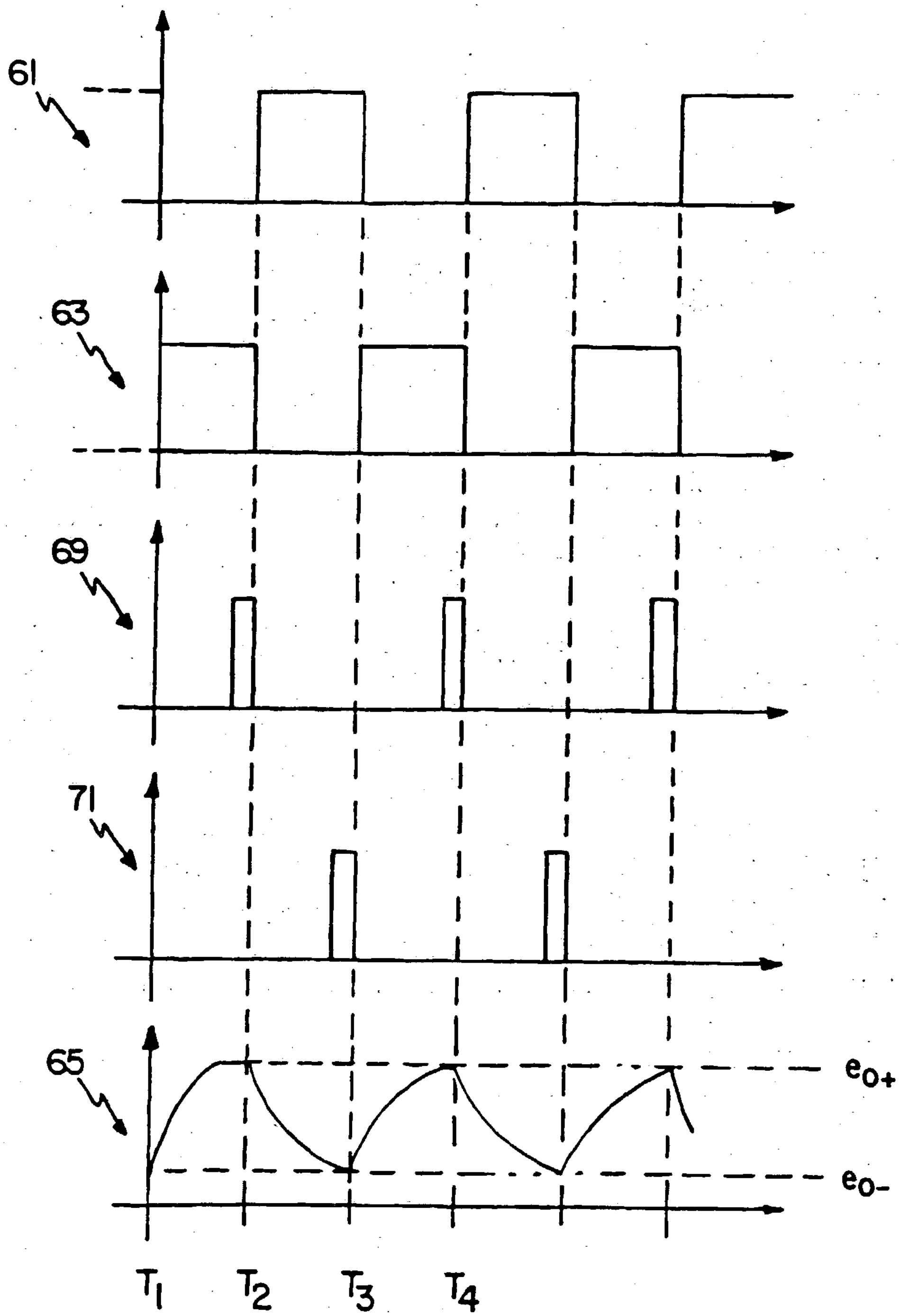


Fig. 3

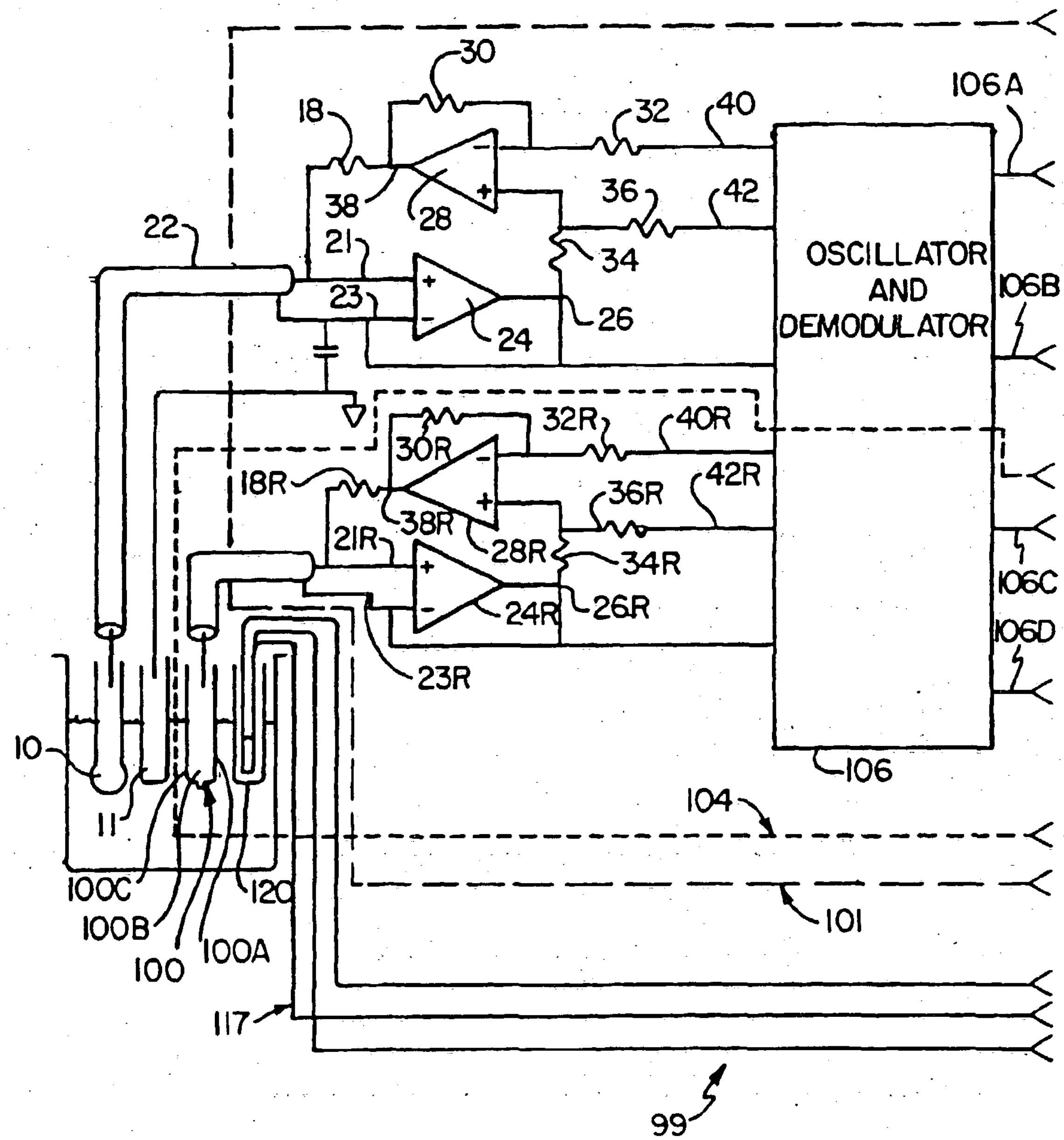

30
18
32
40
106A
36
42
38
28
22
21
34
OSCILLATOR AND DEMODULATOR
23
26
106B
24
32R
40R
30R
18R
36R
42R
38R
28R
21R
34R
106C
24R
26R
106D
23R
10
106
104
11
100C
120
101
100B
100
100A
117
99

Fig 4A

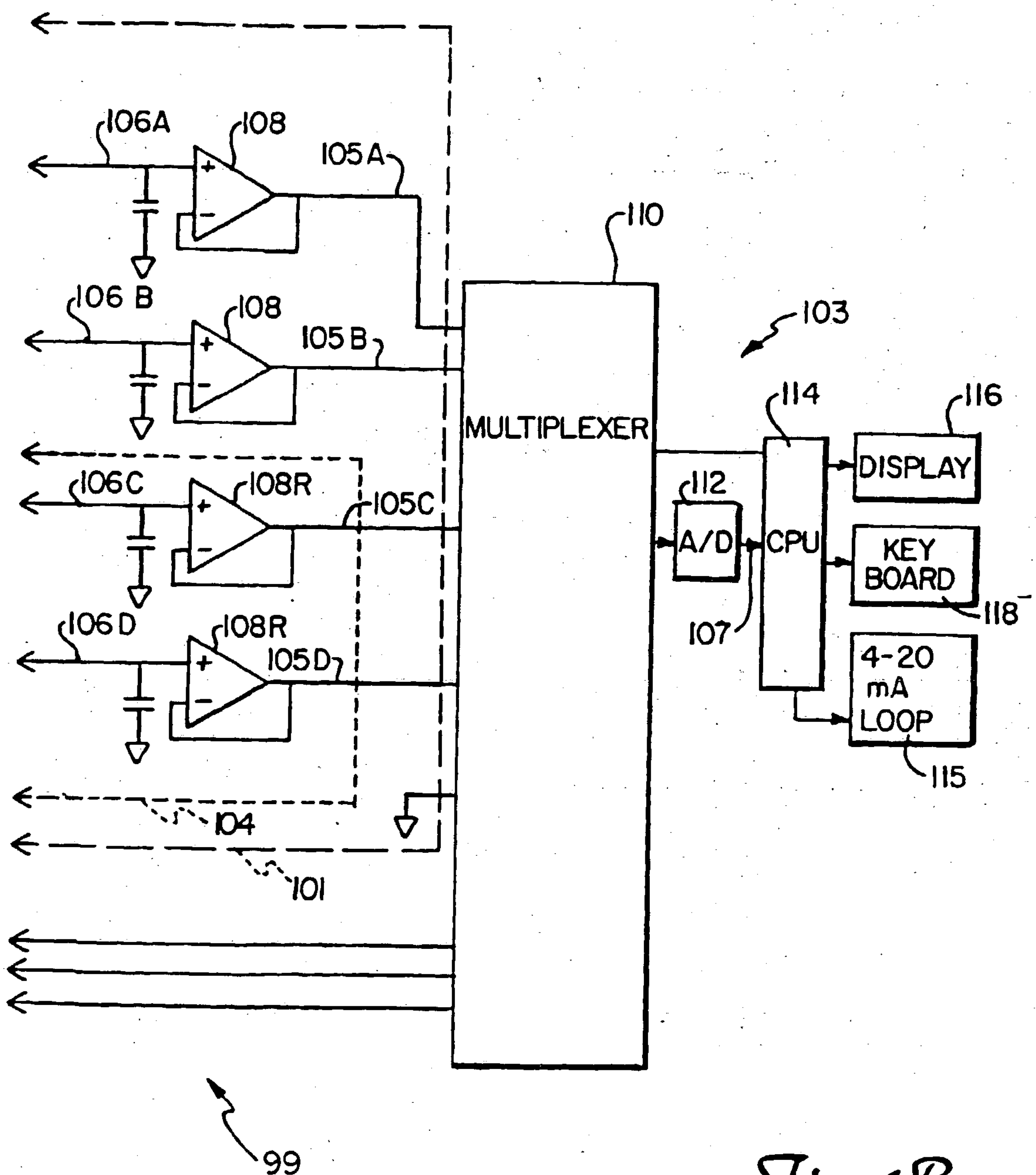
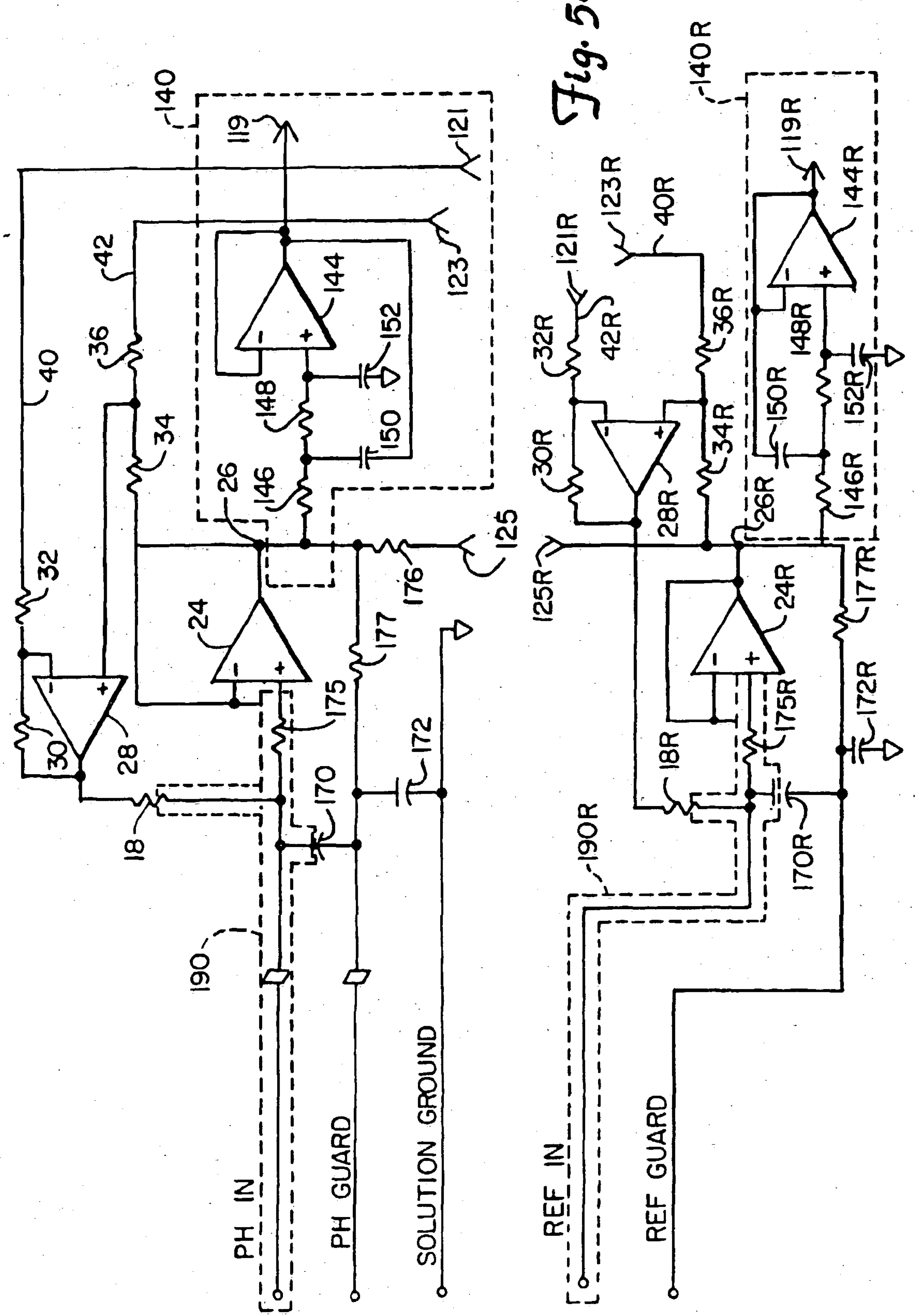

106A
108
105A
110
106 B
108
105 B
103
MULTIPLEXER
114
116
DISPLAY
106C
108R
105C
112
A/D
CPU
KEY
BOARD
118
107
106 D
108R
105D
4-20
mA
LOOP
115
104
101
99

Fig. 4B


PH IN
PH GUARD
SOLUTION GROUND
REF IN
REF GUARD
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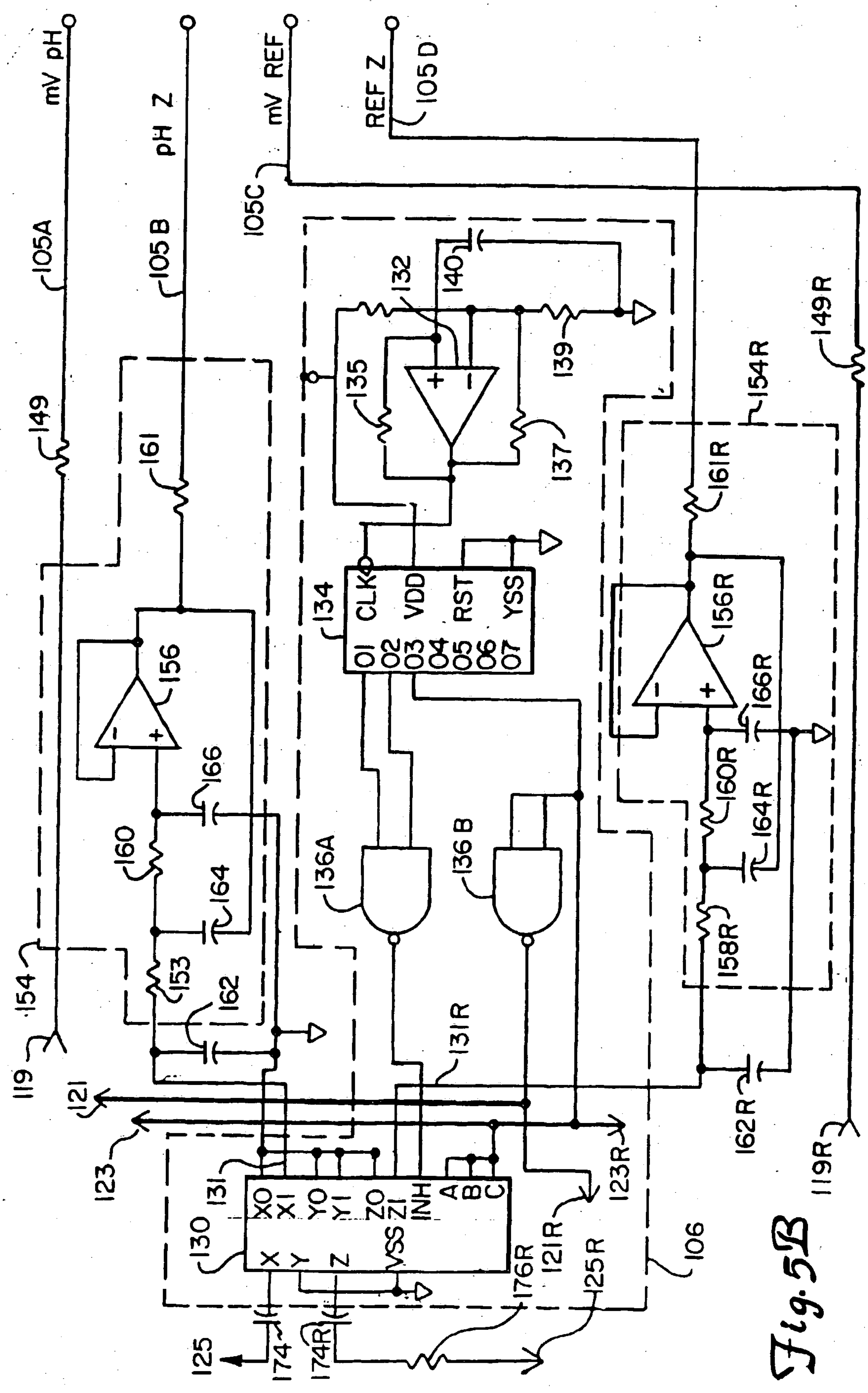
150
152
144
140
119
121
123
125
175
170
177
176
172
190R
18R
170R
175R
172R
177R
24R
26R
125R
28R
30R
32R
42R
121R
123R
40R
36R
34R
146R
150R
148R
152R
144R
119R
140R

Fig. 5A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pH Z
mV REF
REF Z
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105B
105C
105D
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161
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121
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132
134
135
136A
136B
137
139
140
153
156
160
162
164
166
174
174R
176R
106
CLK
VDD
RST
YSS
O1 O2 O3 O4 O5 O6 O7
X0 X1 Y0 Y1 Z0 Z1 INH A B C
X Y Z VSS
131R
149R
154R
156R
158R
160R
161R
162R
164R
166R
119R
121R
123R
125R

Fig. 5B